(NREL) / DOE Subcontract with Genencor for "Cellulase Cost Reduction for Bioethanol"

Enzyme Sugar Platform and
Advanced Pretreatment Interim
Stage Reviews

May 1-2, 2003

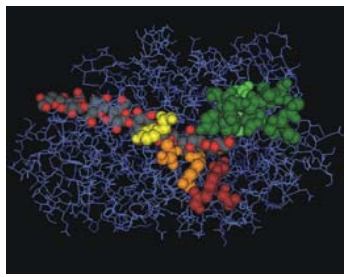
Genencor International, Inc.

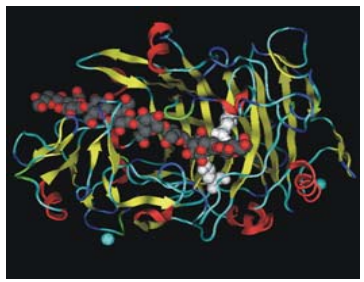
Innovative by Nature™

Genencor International, Inc.®

Improved Low Cost Cellulase for Biomass Conversion

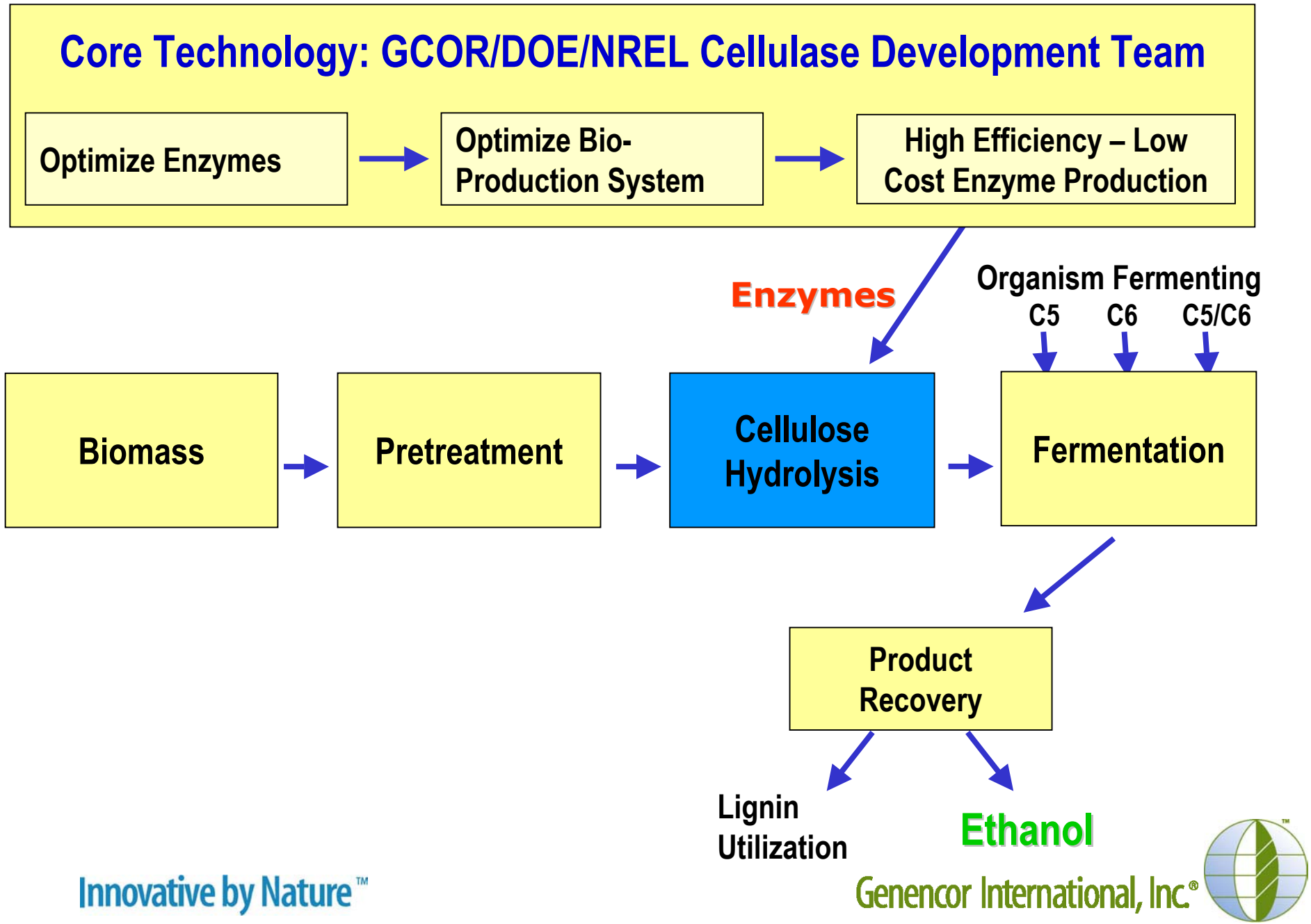
- Project background and strategy
- Progress to date
- What this progress means





Project Background

- National Renewable Energy Laboratory (NREL) / DOE Subcontract with Genencor for "Cellulase Cost Reduction for Bioethanol"
- Focus:
  - Economically acceptable enzymatic conversion of cellulosic biomass to glucose for fermentation to ethanol or other products
  - Renewable fuel and chemical alternative to petroleum
- Goal: 10-Fold reduction in cost of enzymes for biomass conversion
  - Project start date: April 27, 2000
  - Duration: 38 months June 26, 2003

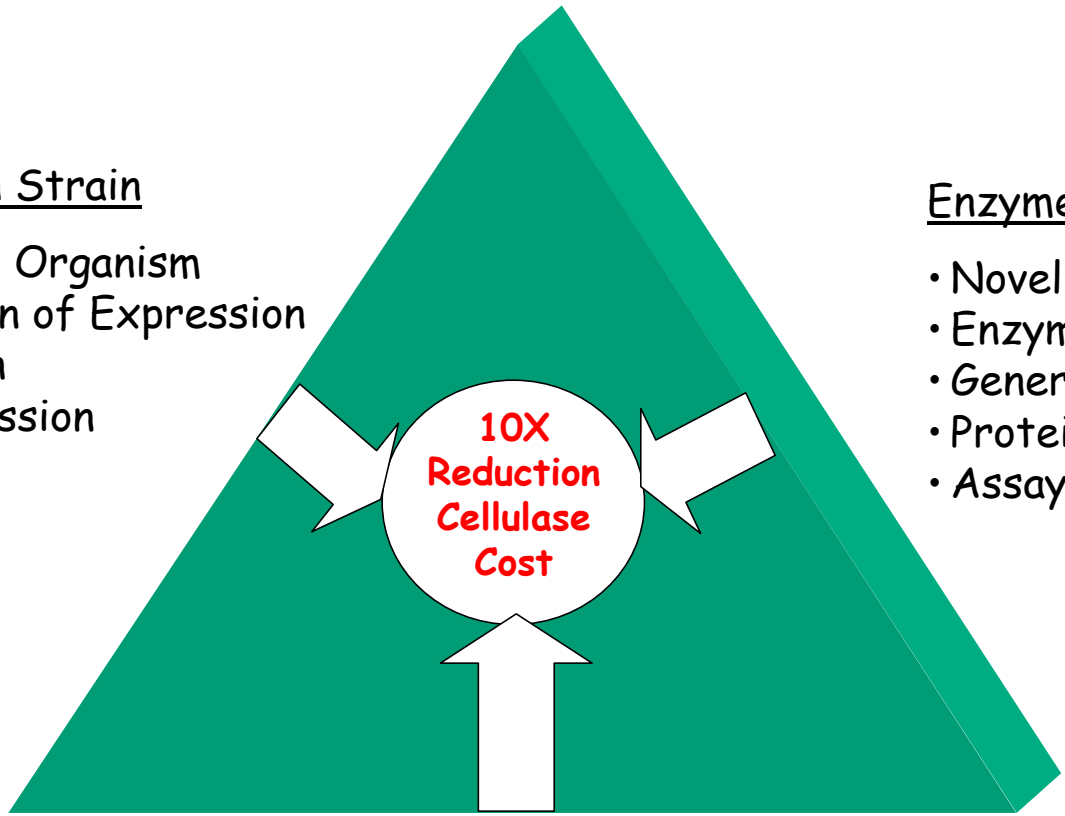

Core Technology: GCOR/DOE/NREL Cellulase Development Team
Optimize Enzymes
Optimize Bio-Production System
High Efficiency – Low Cost Enzyme Production
Enzymes
Organism Fermenting
C5
C6
C5/C6
Biomass
Pretreatment
Cellulose Hydrolysis
Fermentation
Product Recovery
Lignin Utilization
Ethanol
Innovative by Nature™
Genencor International, Inc.®

Strategy

- 10X cost reduction goal achievable only by BOTH:
  - Improved production economics (reduced $/gm enzyme)
  - Improved cellulase performance (reduced gm enzyme/gal EtOH)

$$\text{Effective cellulase cost}\left(\frac{\$}{\text{gal EtOH}}\right)=\left(\frac{\$}{\text{gm enzyme}}\right)\cdot\left(\frac{\text{gm enzyme}}{\text{gal EtOH}}\right)$$

Strategy: Integrated Plan of Action



Production Strain

- Choice of Organism
- Regulation of Expression
- Induction
- De-repression
- Genomics

Enzyme Performance

- Novel Cellulolytic Activities
- Enzyme Discovery
- Generation of Diversity
- Protein Engineering
- Assays and Screens

Production Process

- Host Engineering
- Fermentation Process Development
- Breakthrough Production Economics
- Product Recovery Manufacturing Economics of Scale

Bottom line

- Genencor has surpassed the NREL/DOE Subcontract 10X goal

- ~12-Fold reduction in cost of enzymes for biomass conversion has been achieved to date

Summary

- Improved production economics (5X)
  - Process and strain enhancements
  - Functional genomics identified many *T. reesei* genes for targeted strain improvement
- Improved Cellulase Performance (2-3X)
  - Functional Genomics identified several novel *T. reesei* cellulase components
  - Improved CBHI proteins engineered with increased activity and stability
  - Other enzyme recruitments

What we developed

- A cellulase enzyme system that targets the future industry of biomass conversion to fermentable sugars / EtOH
- A production organism and a process to produce the enhanced cellulase system

What this means (in practical terms)

- An enzyme cocktail has been developed which is tailored to dilute acid pretreated corn stover (NREL model process)
- A production strain and system to produce it has been developed
- Enzyme cost per gal EtOH produced (per NREL calculations) is ~12X below existing commercial cellulases
- Projected cost of enzymes for biomass ethanol of $0.30 - 0.40/gal EtOH (NREL process and conditions)

What 12X means (in practical terms)

$$\text{Effective cellulase cost}\left(\frac{\$}{\text{gal EtOH}}\right)=\left(\frac{\$}{\text{gm enzyme}}\right)\cdot\left(\frac{\text{gm enzyme}}{\text{gal EtOH}}\right)$$

- First term - enzyme production cost
  - Audited by NREL
- Second term – enzyme performance
  - Enzyme loading (NREL experimentally validated) and calculated yield of EtOH on sugars
- Overall cellulase cost
  - From subcontract metric - $0.40/gal EtOH
  - From 2002 design report - $0.30/gal EtOH
    (http://www.nrel.gov/docs/fy02osti/32438.pdf)

What 12X means (in practical terms)

$$\text{Effective cellulase cost}\left(\frac{\$}{\text{gal EtOH}}\right) = \left(\frac{\$}{\text{gm enzyme}}\right)\cdot\left(\frac{\text{gm enzyme}}{\text{gal EtOH}}\right)$$

- First term - enzyme production cost
  - Audited by NREL
- Second term – enzyme performance
  - Enzyme loading (NREL experimentally validated) and calculated yield of EtOH on sugars
- Overall cellulase cost
  - From subcontract metric - $0.40/gal EtOH
  - From 2002 design report - $0.30/gal EtOH
    (http://www.nrel.gov/docs/fy02osti/32438.pdf)

What 12X means (in practical terms)

$$\text{Effective cellulase cost}\left(\frac{\$}{\text{gal EtOH}}\right)=\left(\frac{\$}{\text{gm enzyme}}\right)\cdot\left(\frac{\text{gm enzyme}}{\text{gal EtOH}}\right)$$

- First term - enzyme production cost
  - Audited by NREL
- Second term – enzyme performance
  - Enzyme loading (NREL experimentally validated) and calculated yield of EtOH on sugars
- Overall cellulase cost
  - From subcontract metric - $0.40/gal EtOH
  - From 2002 design report - $0.30/gal EtOH
    (http://www.nrel.gov/docs/fy02osti/32438.pdf)

What 12X means (in practical terms)

$$\text{Effective cellulase cost}\left(\frac{\$}{\text{gal EtOH}}\right) = \left(\frac{\$}{\text{gm enzyme}}\right) \cdot \left(\frac{\text{gm enzyme}}{\text{gal EtOH}}\right)$$

- First term - enzyme production cost
  - Audited by NREL
- Second term – enzyme performance
  - Enzyme loading (NREL experimentally validated) and calculated yield of EtOH on sugars
- Overall cellulase cost
  - From subcontract metric - $0.40/gal EtOH
  - From 2002 design report - $0.30/gal EtOH

    (http://www.nrel.gov/docs/fy02osti/32438.pdf)

Where do we go from here?

- Still need to go ~3-4X to get to $0.10/gal EtOH (will be highly process dependant)

- This is aggressive but achievable!